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DEVELOPMENT OF SIMPLIFIED DESIGN AIDS BASED ON THE RESULTS OF SIMULATION ANALYSIS*

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Summary

The Solar Load Ratio method for estimating the performance of passive solar heating systems is described. It is a simplified technique which is based on correlating the monthly solar savings fraction in terms of the ratio of monthly solar radiation absorbed by the building to total monthly building thermal load. The effect of differences between actual design parameters and those used to develop the correlations is estimated afterwards using sensitivity curves. The technique is fast and simple and sufficiently accurate for design purposes.

1. INTRODUCTION

It is now generally accepted that computer simulation analysis using thermal-network type of mathematical representations of the energy flows is an accurate method of predicting the performance of passive solar buildings. The analysis is generally done using hourly solar and weather data. This is fine if the designer has the computer, the capability, and the inclination to take this approach. But even under the best of circumstances it is costly and time consuming. Most designers ask for simpler techniques which are amenable to analysis using hand calculators in which estimates can be generated in a few minutes. Correlation techniques have emerged as a reasonable procedure which meet these requirements and give reasonable accuracy.

2. CORRELATION METHODS

In a correlation technique one seeks to relate a parameter of interest, such as solar savings fraction, to one or more correlating parameters (generally dimensionless). Success is much more likely if the correlating parameters chosen preserve some essence of the overall physics governing the energy balances.

For solar energy systems it has been appropriate to correlate on the basis of a one-month interval, that is, to use monthly weather data to predict monthly performance. A month has been found to be a particularly convenient time interval, being long enough that statistical variations tend to average out and short enough so that the basic

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weather statistics are stationary. Furthermore, only eight to twelve calculations are then required in order to predict annual performance. The prediction of monthly performance leads to relatively high standard errors (± 8%, typically) but annual performance is predicted with a standard error of only ± 3%, typically. This is adequate for design purposes, being significantly less than the year-to-year variation which can be anticipated.

A second feature is that the correlations are done using "data" developed from hour-by-hour computer simulations. Thus the correlation techniques are a second-generation analytical procedure, and their results are intrinsically no better than those obtained from simulations. The correlation techniques, however, are at least two orders of magnitude easier to use in terms of the computing power and the computing time required.

3. THE SOLAR LOAD RATIO (SLR) TECHNIQUE APPLIED TO PASSIVE SYSTEMS

The SLR method depends on the use of a single correlating parameter defined as follows:

$$SLR = (\text{solar absorbed})/(\text{net reference load})$$

As mentioned, the correlation time is one month so that each of the parameters in the above equation are for a one month period. Both the numerator and denominator are in energy units so SLR itself is dimensionless. Physically it relates the monthly solar energy absorbed by the building to the net load which would be experienced by a comparable building without the passive solar element.

The parameter which is correlated is the solar savings fraction, SSF, defined as follows:

$$SSF = 1 - (\text{auxiliary})/(\text{net reference load})$$

The definition of the terms used in these two relations is important, but it is not the purpose here to discuss this in detail. The various terms are defined in the DOE Passive Solar Design Handbook, Volume II, Passive Solar Design Analysis (1), where the distinctions between various ways of estimating load are discussed. The key point is that the solar savings fraction is intended to identify the savings due to adding a particular passive solar element to a building. The net reference load is the heating requirements of a comparable non-solar building, that is, a building which is otherwise identical but without the passive solar element. Presumably the solar element would replace a normal wall with the normal complement of windows.

In choosing SSF as the correlated parameter, it was intended to find a convenient dimensionless variable and not to imply that SSF is an important figure of merit. The important objective is to minimize auxiliary heat, given by:

$$\text{auxiliary} = (1\text{-}SSF) \times (\text{net reference load})$$

where the net reference load is estimated simply as the product of the building load coefficient (excluding the solar wall) times the heating degree days. This has been found to be reasonably accurate if the degree days are calculated using an appropriate base temperature which accounts for both the thermostat setting and the extraneous internal heat generation in the building.

In developing the correlations, a functional form was used which allows the selection of four different coefficients. These were adjusted in order to obtain a least-square error in the annual solar savings fraction.

Typically the correlations are done using hour-by-hour calculations from many different cities with four different values of building load coefficient in each city. This gives a reasonably diverse ensemble of "data" points. The standard deviation of the error in prediction of solar savings fraction, compared to the hour-by-hour simulations, is typically about 3 to 4%.

The SLR method has been applied to a variety of passive systems. A different correlation is required for each different passive system but each correlation applies to all climates. Thus far, direct gain, Trombe wall, and water wall configurations have been studied and these correlations are given in the Appendix. The results are being widely used within the passive solar design community. The method is the basis for the design techniques described in the Passive Solar Design Handbook.

4. REFERENCE DESIGNS

The hour-by-hour simulations which are used as the basis for the correlations are done with a detailed model of the building in which all of the different design parameters are specified. These parameters are given in the Appendix. The only design parameter which is changed is the ratio of the glazing area to the building load coefficient of the building (the Load Collector Ratio, LCR). Typically about four different values of LCR were chosen so that the correlation should adequately reflect variations in this key parameter.

Thus the correlations do not allow the designer to estimate performance variations due to changes in any of the many other design parameters and the correlations relate only to the reference design used in the simulations.

In order to overcome this difficulty, sensitivity calculations have been done using the hour-by-hour simulation codes. The procedure is to perform a series of year-long simulations for several different values of one of the design parameters, holding all other parameters at the reference level. These results are generally presented in graphical form and allow the designer to see the effect of changing one particular design parameter. This procedure is followed for each of the different design parameters. A major part of the Passive Solar Design Handbook is taken up with such sensitivity studies for the direct gain and thermal storage wall systems.

5. ATTACHED SUNSPACES

In a recent publication (2) McFarland and Jones have given correlations for attached sunspaces. These results indicate that a sloping glazing (about 50 degrees) is much more effective than vertical, that heating performance is improved by using opaque insulated end walls rather than glazed end walls, and that overall performance in heating the attached building is very comparable to that of a Trombe wall.

As an example of the correlation results, the following graphs give the simulation results (Fig. 1) and correlation accuracy (Fig. 2) for one reference design, the case of an attached sunspace with sloping glazing

(50 degrees), masonry thermal storage between sunspace and house, opaque end walls, and no night insulation.

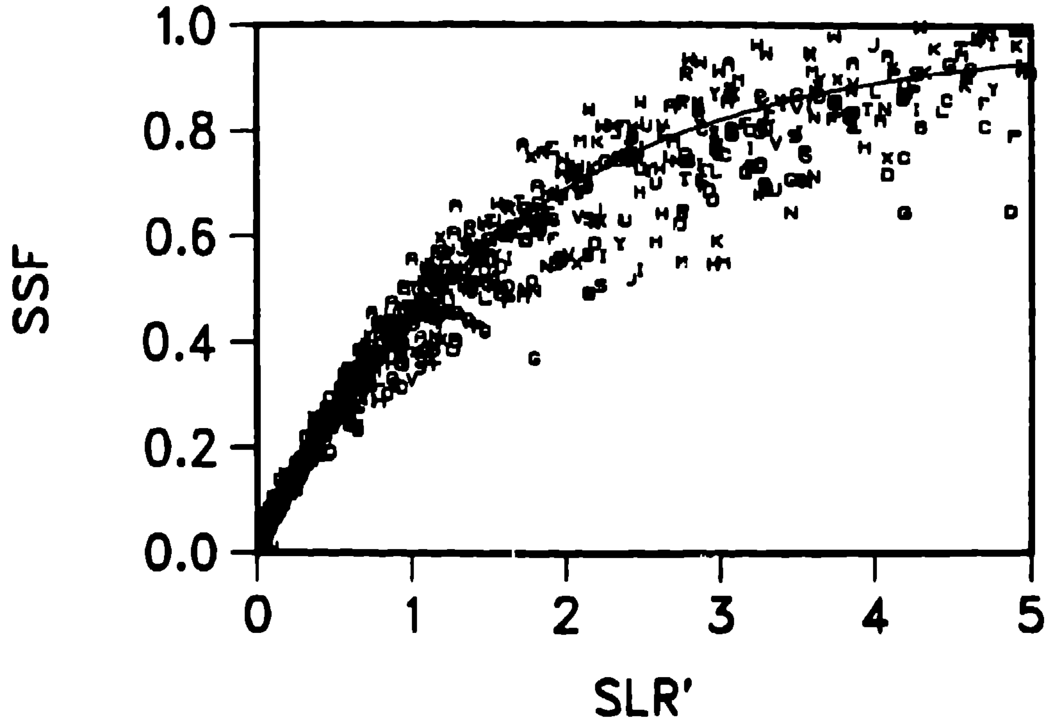

Fig. 1. Monthly SSF vs SLR'. See Ref. 2. for the definition of SLR' as it applied to sunspaces.

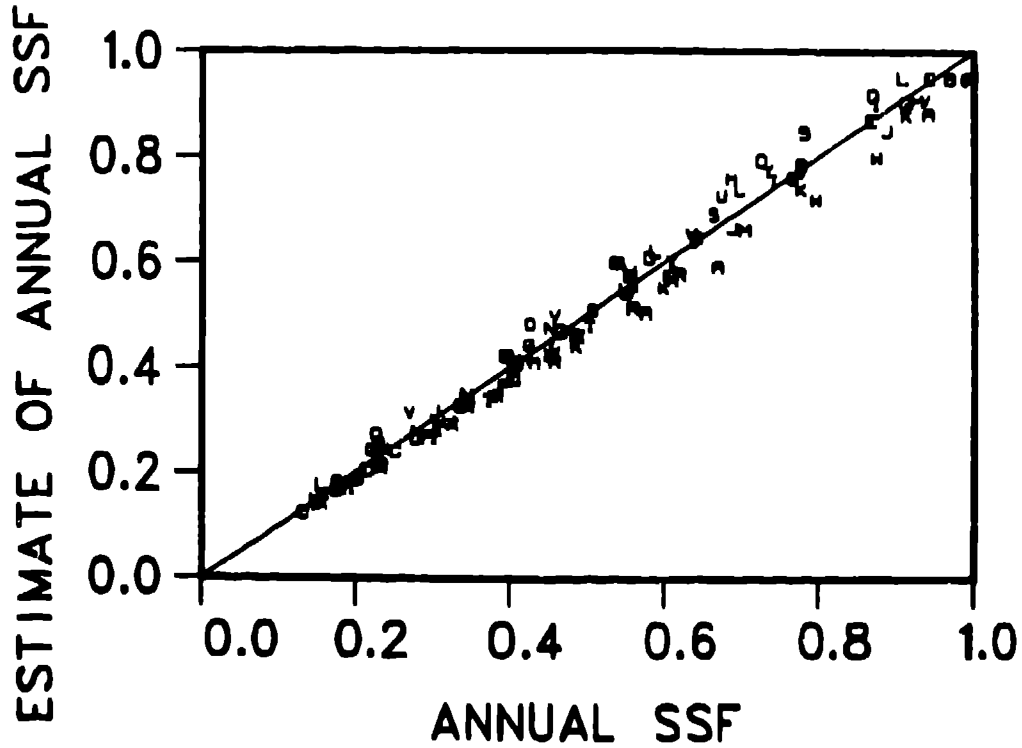

Fig. 2. Comparison of annual SSF estimated by SLR method and calculated by simulation. The standard deviation of the error is 0.032 over an ensemble of four LCR's each in 24 cities.

More recent results, as yet unpublished, indicate even better performance for a "semi-enclosed" sunspace, that is, a geometry in which the house wraps around the sunspace enclosing the east and west ends. This geometry provides the highest performance of all passive solar geometries studied to date by LASL.

Attached sunspaces will be discussed extensively in a forthcoming added volume of the Passive Solar Design Handbook.

6. PERFORMANCE TABLES FOR PARTICULAR LOCATIONS

Since the correlation curves are developed using weather data from a variety of different locations, these curves can be used in locations which have a climate type encompassed by the original grouping of cities. However, an annual solar savings fraction calculation involves summing up the results of twelve monthly calculations. For a particular city the results depend only on the ratio of building load to collector area (LCR), on the system type, and on the temperature base used in the calculation of the degree days. Thus it is possible to make up tables for a particular city which relate the solar savings fraction to the LCR for the various systems, assuming one particular base temperature. These tables could be re-done for various base temperatures. These tables are much easier to use than the SLR correlations.

LCR tables have been made up for 216 different locations in the U.S. and southern Canada based on the SOLMET weather data using an 18.3°C base. These are published in the Passive Solar Design Handbook, Appendix F, for direct gain and thermal storage wall systems. These tables form the basis of a simplified design procedure described in the Handbook.

As an alternative to presenting the SSF results in terms of LCR, many people have expressed a preference for using the reciprocal, collector load ratio, CLR = 1/LCR, as the independent parameter. Fig. 3 shows the performance of four attached sunspace options in Dodge City, Kansas, plotted vs CLR ($^{o}Cm^{2}/W$) showing the comparison between the results of hourly simulations (solid curves) and the estimates using the SLR correlations (dashed curves). The geometry is the same as for Figs. 1 and 2. I.E. stands for insulated end walls and G.E. for glazed end walls.

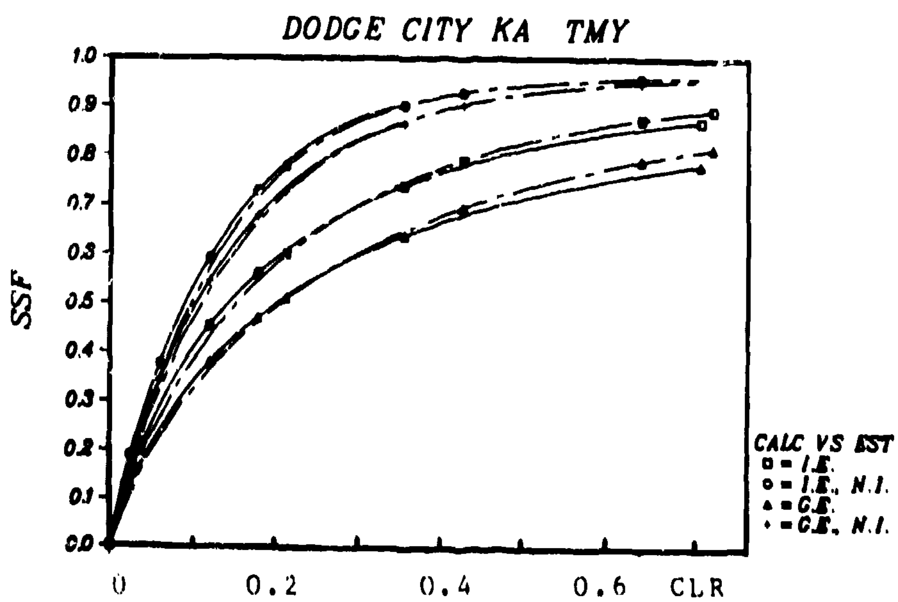

Fig. 3. Comparison of simulation and correlation results for an attached sunspace in Dodge City, Kansas.

7. DECIDING BETWEEN CONSERVATION AND PASSIVE SOLAR OPTIONS

Every good passive solar designer knows that energy conservation must be a cornerstone of the building design. But at some point the trade-off between additional energy conservation and passive solar collection aperture must be addressed. If a handy method is available for estimating performance, then this trade-off can be done in an analytical way. For example, if the correlation techniques can be incorporated into a hand held calculator or microcomputer routine, then the designer can obtain very quick turn-around in the calculations, and the trade-off between conservation and solar options can be easily and quickly assessed.

A simple technique has been developed which can be used to determine the optimum mix between conservation and solar strategies (3). In order to obtain an answer, the cost characteristics of both the passive solar aperture and the energy conservation features are needed. This information will generally be in the form of the cost per R per unit area for the wall and ceiling insulation, the cost per additional glazing for windows, the cost of reducing infiltration (including the cost of adding an air-to-air heat recovery unit if needed) and also the cost per unit area for the passive solar collection aperture. Given this information the method provides simple equations which can be used to trace out the optimum-mix line for a particular locale. This will provide information to the designer early in the design process to serve as a guide in the decision making.

8. CONCLUSIONS

Correlation methods of prediction have advantages in greatly simplifying the time and complexity of performance predictions but are severely constrained in the number of variables which can be considered. Their accuracy is generally adequate for design purposes provided they are applied to buildings which correspond reasonably closely to the reference designs used in developing the correlations. The most simplified correlation procedures (such as the SLR method) are particularly amenable to use with hand calculators. When reporting the results of these calculations, the designer should be especially careful to specify the range of validity of the analysis, especially as pertains to both operating characteristics and design parameters.

Correlation techniques are especially amenable to use in microcomputer routines which can be used in a design office. Very quick answers can be obtained during the schematic design and design development phases of a building to aid in deciding between different design options. This would include trade-offs between various conservation options and passive solar options.

9. ACKNOWLEDGEMENTS

The author gratefully acknowledges the assistance of James Hedstrom, Robert McFarland, William Wray, and Dennis Barley in the development of the correlation techniques. Figs. 1-3 are from Ref. 2.

10. REFERENCES

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2. R. D. McFarland and R. W. Jones, "Performance Estimates for Attached-Sunspace Passive Solar Heated Buildings", Proceedings of the 1980 Annual Meeting of AS/ISES, Phoenix, Arizona, June 2-6, 1980.

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11. APPENDIX

Correlations

For each month of the heating season, the ratio S/DD is determined, where S is the total monthly solar radiation transmitted through one square meter of south-facing, vertical double glazing and DD is the heating degree days.

Then the Solar Savings Fraction (SSF) is determined for each month as follows:

$$SSF = 1 - K\,(1-F), \text{ where}$$
$$F = A\,X, \text{ for } X < R$$
$$F = B - C\,\exp(-DX), \text{ for } X > R$$
$$F \leq 1.000 \text{ for large } X.$$

and where

$$K = 1 + G/LCR$$
$$X = (S/DD)/(LCR \times K)$$

(X is the "Solar Load Ratio")

$$LCR = \frac{\text{building load coefficient, exclusive of solar glazing}}{\text{solar collection area}},\ W/^{\circ}Cm^2$$

(LCR is the "Load Collector Ratio")

Constants for the various passive system types are as follows:

	G	R	A	B	C	D
DG	2.51	0.5	0.5213	1.0133	1.0642	0.6927
DGNI	0.57	0.7	0.5420	0.9866	1.1479	0.9097
TW	0.85	0.6	0.3698	1.0408	1.0797	0.4607
TWNI	0.12	1.0	0.4556	0.9769	1.2159	0.8469
WW	1.18	1.3	0.4025	0.9872	1.5053	0.3054
WWNI	0.17	1.2	0.4846	0.9794	1.8495	1.2795

The annual SSF is then obtained from the sums of the monthly values, as follows:

$$\text{Annual SSF} = \frac{\sum_i \text{SSF}_i \cdot \text{DD}_i}{\sum_i \text{DD}_i}$$

Here, DG, TW, AND WW indicate direct gain, Trombe wall, and water wall, respectively. NI indicates night insulation.

Most passive designs consist of a mixture of the basic approaches. Few Trombe walls are without some direct gain component. Most water walls are spread-apart tubes or other containers which allow some direct heating. The recommended procedure is to compute a single SLR, based on the total solar gain through all glazing divided by the total thermal load, and then compute a weighted-average SSF. This is determined by computing a separate SSF for each design approach and averaging between them based on the relative proportion of each glazed area.

Reference Designs

The correlation curves are determined for a set of "reference" configurations defined as follows:

Double glazing, normal transmittance = 0.747 , 6.4 mm spacing
Night insulation (when used) is 0.63 W/^{o}Cm^2; 5:00 pm to 8:00 am
Thermal Storage = 920000 J/^{o}C per m^2 of glazing
  Water wall: equivalent to 216 mm of water
  Trombe wall: 450 mm thickness
Thermal conductivity = 1.73 W/m^{o}C
Trombe wall has vents, upper and lower, each 3% of the wall area, having backdraft dampers.
Direct Gain = exposed surface = 3 x glazed area 150 mm thickness
Other building mass is negligible
Wall-to-room conductance = 5.7 W/^{o}C m^2

Auxiliary maintains an internal building temperature above 18.3^{o}C. Heat is dumped to maintain the building temperature below 23.9^{o}C. No internal building heat generation was modeled.